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COMBINING ABILITY AND HETEROSIS IN TOMATO UNDER HIGH TEMPERATURE CONDITIONS

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ABSTRACT: *This investigation was conducted during 2014 and 2015 at Kalubia governorate to develop promising hybrids of tomato (Solanum lycopersicum L.) for yield and fruit quality characters under high temperature stress in Egypt using Line x Tester matting design. All studied traits, i.e., fruit set, total yield, marketable yield, average fruit weight, fruit shape index, fruit firmness, number of locules, total soluble solids (TSS%), vitamin C content and titratable acidity have closer values of* $\sigma^2 g$ *and* $\sigma^2 p$*, meanwhile, the G.C.V. and P.C.V.% which was confirmed by the estimated G.C.V./P.C.V. ratios and high broad sense heritability (BSH) values suggest less effect of environment and the large portion of* $\sigma^2 p$ *was due to the* $\sigma^2 g$ *on these traits, except number of locules and titratable acidity traits which was affected by both genetic and environmental factors. The ratio of* $\sigma^2 GCA$ / $\sigma^2 SCA$ *were found less than unity (<1) indicating the preponderance of non additive gene actions over the additive ones for all the studied traits. The prevalence of the non-additive variance suggested heterosis breeding approach is effective way for improvement of these traits. Most of the traits exhibited significant hybrid vigor for some of crosses based on the better-parent. The lines Ent 5 and Ent 17 and the tester TLB 111 showed maximum positive GCA effects for most of the important traits. So, these parents could be successfully used in future for breeding programs. Among all hybrids, Ent 3 × 99S-C-39, Ent 5 × 99S-C-39 and Ent 31 × TLB 111 exhibited significant SCA effects for both total and marketable yield characters under heat stress. So, these hybrids could be used in future for breeding to these traits.*

Key words: *Tomato, Solanum lycopersicum, Heat tolerance, Heterosis, Combining ability, heritability, GCA, SCA.*

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops grown throughout the world because of its wider adaptability, high yielding potential and suitability for uses as salad, cooked or processed into several preferred products like ketchup, juice, puree, sauce and whole canned fruit. In Egypt, shortage of tomatoes production is common due to high temperatures in late summer season. Tomato is adapted to a wide range of climates while fruit set is limited to a somewhat narrow range. High temperature during reproductive development caused significant increment in flower drop and significant decrease in fruit set (Berry *et al* 1988) and consequently fruit yield decreased to a great extent. At high temperature, the reproductive part of the flower is adversely affected. Stigma tube elongation, poor pollen germination, poor pollen tube growth and carbohydrate stress are the main reasons for poor fruit set at high temperature in tomato. El-Ahmadi and Stevens (1979) also said that fruit setting in tomato is interrupted at temperature above 26 °C and 20 °C day/night and is often completely arrested at temperature above 38/27 °C day/night. However, Metwally *et al* (1988) indicated that for optimum fruit setting, tomato plants require night temperature of 14-20°C and day temperature of 25-30°C. When night or day temperature was higher or lower than this rang fruit setting was reduced or completely terminated. However, temperature higher than 34/20°C (day/night) or a period of 4 hours at 40°C cause blossom drop in most cultivars.

The knowledge of genetic structure and mode of inheritance of different characters helps breeders to employ suitable breeding methodology for their improvement. In any breeding programme, the proper choice of parents based on their combining ability is a prerequisite. Combining ability is an important in plant breeding since it provides information for selection of parents and also provides information regarding nature of gene actions. In this direction, the concept of general (GCA) and specific (SCA) combining abilities helps the breeder to decide upon the choice of parents for hybridization and also gives information on gene action, which helps in understanding the nature of inheritance of the characters (Sprague and Tatum 1942). Griffing (1956) stated that GCA effects were due to additive type of gene action and SCA effects were due to non-additive (dominant or epistatic) gene action. In this context, Line × Tester mating design proposed by Kempthrone (1957) helps the breeders by providing information on the combining ability status of genotypes (parents and hybrids) used and also on the nature of gene action involved.

In plant breeding, tomato hybrids had contributed a lot in terms of production. The estimation of heterosis for yield and fruit quality characters is useful to judge the best hybrid combination for exploitation of superior hybrids. Heterosis over better parent on tomato was reported for some traits, *i. e.,* average fruit weight, TSS and total yield by Mondal *et al* (2009), for fruit set, TSS, firmness, total yield, by Shalaby (2012), for fruit weight, fruit yield per plant, fruit firmness and total soluble solids, by Saeed *et al* (2014) and for fruit firmness, TSS, average fruit weight, yield per plant by Khalil *et al* (2015). However, heterosis was found absent for average fruit weight (Shalaby 2012), for fruit yield, TSS, and fruit firmness (Kalenahalli and Gowda 2013) and for fruit set trait (Khalil *et al* 2015).

Several studies of combining ability for yield and fruit quality characters are available in tomato. The additive variance was larger than non-additive variance and the ratio of additive variance and non additive genetic variance is more than unity, establishing the predominance of additive gene action in the inheritance of the traits average fruit weight, total yield per plant, TSS, ascorbic acid, titratable acidity (Kumar *et al* 2013), average fruit weight (Shankar *et al* 2013), total yield (Saeed *et al* (2014) TSS, fruit acidity and ascorbic acid (Dagade *et al* 2015) and fruit firmness (Khalil *et al* 2015). Hence, significant advancement could be achieved in the segregating generations using simple selection procedures or conventional breeding methods such as pedigree and bulk selection, which are useful for accumulation of desirable genes for these traits.

However, non-additive genetic variance had greater estimates than additive genetic variance and the ratio of additive variance and non additive genetic variance is less than unity, establishing the predominance of non additive gene action in the inheritance of the traits total soluble solids and tritable acidity (Mondal *et al* 2009), yield per plant (Dagade *et al* 2015 and Shankar *et al* 2013), total yield, average fruit weight, fruit firmness, TSS, ascorbic acid (Kansouh and Zakher 2011), total soluble solids, ascorbic acid, acidity, average fruit weight, fruit yield per plant (Katkar *et al* 2012), TSS, fruit firmness, yield/plant (Kalenahalli and Gowda 2013), fruit weight, fruit firmness and total soluble solids (Saeed *et al* (2014) and TSS, fruit set, average fruit weight and yield per plant (Khalil *et al* 2015). The presence of non-additive gene action suggests that heterosis breeding method is effective for improvement of these traits.

Low values of difference between genotypic coefficient of variation (GCV%) and phenotypic (PCV%) coefficients of variations, as well as, high broad sense heritability (BSH) for the traits total yield, average fruit weight, fruit firmness, TSS, acidity and ascorbic acid contents were observed by Kansouh and Zakher (2011) and Salib (2012).

The maximum day and minimum night temperatures in Egypt are frequently getting higher than 30 °C and 20°C, respectively, during summer season. Therefore, the objective of the present study was to identify breeding lines/varieties having good combining ability effects and best cross combinations for developing promising hybrids with yield and fruit quality characters under high temperature stress using Line x Tester mating design.

MATERIALS AND METHODS

This investigation was carried out during the period from 2014 to 2015. Thirteen tomato pure lines were evaluated under high temperatures stress during 2014 in late summer season to insure high degree of homozygosity of each parent before crossing. These pure lines were Ent 2 (L_1), Ent 3 (L_2), Ent 5 (L_3), Ent 8 (L_4), Ent 9 (L_5), Ent 12 (L_6), Ent 17 (L_7), Ent 28 (L_8), Ent 31 (L_9) and Ent 37 (L_{10}) which was used as females (Lines) and TLB 111 (T_1), TLB 182-1 (T_2) and 99S-C-39 (T_3) which was used as males (testers). All these genotypes were produced from previous tomato breeding program by selfing and selection during 6 generations at Vegetable Breeding Dep., Hort. Res. Inst., Agric. Res. Center, Egypt (Abo-Hamda 2004), except the genotypes TLB 111 and TLB 182-1 which were kindly collected from Asian Vegetable Research and Development centre (AVRDC), Taiwan. The females were chosen for genetic studies based on their performance of yield and other desirable economic characters, *viz.*, yield, yield components and fruit quality. Males were chosen as heat resistance sources. Selfing and crosses were made manually using the standard procedure of hand emasculation and pollination in the greenhouse at Kaha Vegetable Research Farm, Kalubia Governorate during the fall season of 2014. Each female line was crossed with the three other males (testers).

Then, all genotypes (13 parents and 30 F_1 hybrids) were evaluated in the open field under high temperature conditions at private farm, Kalubia Governorate during late summer of 2015 season. The nursery of each accession was transplanted in a field in three replicates following randomized complete block design layout. Each genotype was grown on one ridge. The seedlings were planted in rows having 10 plants per row keeping row-to-row and plant-to-plant distances of 80 cm and 40 cm, respectively. Land preparation and field practices were applied according to recommendations of the Egyptian Ministry of Agriculture. Seeding and transplanting dates were at April 3^{th} and May 18^{th}, 2015, respectively. Averages of temperatures during the growing evaluation season of the study at Kalubia governorate were 25/15.2, 29/21.2, 31/24.1, 33/23.5 and 35/24.1°C day/night in April, May, June, July and August, respectively (Central Laboratory for Agricultural Climatic, Ministry of Agriculture and Land Reclamation, Egypt).

Data were recorded on 5 randomly chosen plants/plot for the studied traits: fruit set% which was calculated as the number of fruits set compared with the total number of flowers on the first 3 clusters, total yield (ton/feddan and feddan=4200 m^2), marketable yield (ton/feddan), average fruit weight (g), fruit shape index which calculated as the ratio of fruit length to fruit width and oval fruit shape is usually considered for a ratio greater than 1.2, round shape for a ratio of 0.95-1.2 and oblate shape for a ratio less than 0.95 (Yeager 1937), fruit firmness (g/cm^2), number of locules/fruit, total soluble solids (TSS%), vitamin C content (mg/100 g fresh fruit) and titratable acidity (mg citric acid/100 g fresh fruit).

The data for all traits were analyzed following Kempthorne (1957). Heterosis over better parent was calculated as percent according to Sinha and Khanna (1975).

Heterosis (%) = $[(\overline{F_1} - \overline{BP}) / \overline{BP}] * 100$

Where, $\overline{F_1}$ = mean performance of cross and $\overline{BP}$ = mean performance of better parent

RESULTS AND DISCUSSION

1 - Analysis of variance and mean square values for the mating design Line x Tester:

Data of Table 1 show that the replications had no-significant differences, however, the mean squares of genotypes were significant for all studied traits indicating the presence of adequate genetic variability and the genetic inference could be calculated as the genotypes are partitioned into parents, crosses and their interactions. The mean squares of parents, crosses and parent × crosses interaction were significant in all studied traits, except parent × crosses interaction of fruit firmness, indicating the presence of considerable differences among these genotypes. Therefore, it become statistically valid for the required diversity for the success of the planned crosses. The lines showed significant differences for all the traits, except the non-significant differences for titratable acidity. Also, the testers exhibited significant differences for all the traits, except total yield and number of locules. While, line x tester interaction showed significant differences for all studied traits, except number of locules trait. These results are in agreement with those of Mondal *et al* (2009), Kansouh and Zakher (2011), Katkar *et al* (2012), Kalenahalli and Gowda (2013), Shankar *et al* (2013), Saeed *et al* (2014), Dagade *et al* (2015) and Khalil *et al* (2015) on tomato crop.

2- Components of variance, heritability, components of genetic variance and proportional contribution:

Genotypic and phenotypic variance (σ^2_g and σ^2_p), heritability in broad sense (BSH), genotypic and phenotypic coefficient of variance (G.C.V. % and P.C.V. %) and the ratio of G.C.V./P.C.V. are shown in Table 2. Estimated σ^2_g vs σ^2_p for the studied traits were: 177.13 vs 194.55 for fruit set, 26.105 vs 35.390 for total yield, 18.03 vs 24.35 for marketable yield, 763.38 vs 775.62 for average fruit weight, 0.012 vs 0.014 for fruit shape index, 6758.23 vs 7901.56 for fruit firmness, 0.90 vs 1.56 for number of locules, 0.106 vs 0.146 for TSS%, 7.74 vs 8.46 for vitamin C content and 0.013 vs 0.021 for titratable acidity. In this respect, all the studied traits showed low values of difference between phenotypic and genotypic variance, except number of locules and titratable acidity traits which led to a close correspondence varies between genotypic and phenotypic coefficient of variations (G.C.V and P.C.V %). Also, the G.C.V./P.C.V. ratios for the studied traits showed high values. Estimates of BSH were high for all studied traits, except number of locules and titratable acidity traits, which were moderate. These results indicated more effect of genetic and less effect of environment on these traits.

Generally, the smaller values of differences between σ^2_p and σ^2_g indicated the low environmental effect on all studied character. Also, estimated G.C.V/P.C.V. ratios and BSH confirmed these results. So, the phenotypic values represented truly the genotypic values which indicated that the selection based on the phenotypic values will be effective for improvement of all studied traits. These results are partially agreed with Kansouh and Zakher (2011) and Salib (2012).

The data in Table 2 showed that lines gave variances higher than testers for the characters marketable yield, TSS% and vitamin C content, however, testers gave variances higher than lines for the characters fruit set, total yield, average fruit weight, fruit firmness, number of locules and titratable acidity, meanwhile, they are the same in the trait fruit shape. These results

Table 1. Analysis of variance and mean squares for some tomato characters growing under heat stress.

Sources of variance	DF	Fruit Set	Total yield	Marketable yield	Average fruit weight	Fruit shape	Fruit firmness	No. locules	TSS	Vitamin C content	Titratable Acidity
Replications	2	$7.104^{N.S}$	$29.165^{N.S}$	$2.417^{N.S}$	$36.808^{N.S}$	$0.001^{N.S}$	$3354.023^{N.S}$	$0.068^{N.S}$	$0.046^{N.S}$	$0.215^{N.S}$	$0.006^{N.S}$
Genotypes	42	548.810*	87.600*	60.411*	2302.391*	0.038*	21418.020*	3.352*	0.357*	23.951*	0.046*
Crosses(C)	29	296.988*	28.621*	26.814*	829.826*	0.023*	18871.052*	1.872*	0.258*	29.283*	0.037*
Parents(P)	12	968.115*	82.742*	70.687*	5871.446*	0.075*	29005.192*	6.956*	0.610*	11.599*	0.062*
P vs C	1	2819.988*	1856.272*	911.399*	2178.118*	0.037*	$4234.030^{N.S}$	3.054*	0.196*	17.554*	0.094*
Lines (L)	9	457.963*	26.769*	18.149*	1277.338*	0.029*	32793.833*	4.149*	0.367*	28.420*	$0.013^{N.S}$
Testers (T)	2	646.323*	$23.571^{N.S}$	81.315*	1531.294*	0.075*	52195.300*	$1.492^{N.S}$	1.100*	87.075*	0.043*
L x T	18	177.685*	30.109*	25.091*	528.129*	0.014*	8206.967*	$0.775^{N.S}$	0.111*	23.293*	0.049*
Error	84	17.421	9.286	6.319	12.236	0.001	1143.333	0.656	0.040	0.717	0.008

NS and *: insignificant and significant at 0.05 level of probability, respectively.

Table 2. Components of variance, heritability, components of genetic variance and proportional contribution for some tomato characters growing under heat stress.

Source of Variance	Fruit Set	Total yield	Marketable yield	Average fruit weight	Fruit shape	Fruit firmness	No. locules	TSS	Vitamin C content	Titratable Acidity
Components of variance										
σ^2 g	177.13	26.105	18.030	763.38	0.012	6758.23	0.90	0.106	7.74	0.013
σ^2 p	194.55	35.390	24.350	775.62	0.014	7901.56	1.56	0.146	8.46	0.021
BSH	0.91	0.74	0.74	0.98	0.89	0.86	0.58	0.73	0.92	0.61
G. C. V. %	21.52	28.603	30.548	32.28	11.407	16.80	21.48	7.202	15.50	14.902
P. C. V. %	22.55	33.304	35.501	32.54	12.069	18.16	28.26	8.443	16.20	19.127
G. C. V. / P. C. V.	0.95	0.86	0.86	0.99	0.95	0.92	0.76	0.853	0.96	0.78
Components of genetic variance										
σ^2 Lines (L)	15.62	-0.218	1.874	33.44	0.002	1466.28	0.02	0.033	2.13	-0.001
σ^2 Testers (T)	31.14	-0.371	-0.771	83.25	0.002	2731.87	0.37	0.028	0.57	-0.004
σ^2 GCA (average)	2.23	-0.028	0.032	5.64	0.000	199.39	0.02	0.003	0.11	-0.001
σ^2 SCA (L x T)	131.43	5.91	11.66	353.51	0.01	9508.76	0.45	0.16	14.92	0.01
σ^2 GCA/ σ^2 SCA	0.02	-0.005	0.003	0.02	0.013	0.02	0.05	0.018	0.01	-0.022
Proportional Contribution (%)										
Lines (L)	47.86	29.03	21.01	47.77	39.25	53.93	68.79	44.07	30.12	11.07
Tester (T)	15.01	5.68	20.91	12.73	22.46	19.08	5.50	29.35	20.51	7.97
(L x T)	37.14	65.29	58.08	39.50	38.29	26.99	25.71	26.57	49.37	80.96

indicated the importance of choice the parents. The results in Table 2 indicted that GCA and SCA variances showed wide range of variation for all studied characters. In all studied traits, SCA variances were greater than GCA variances and the ratio of σ^2GCA / σ^2SCA were found less than unity (<1). The higher magnitude of SCA variances indicates the preponderance of non additive gene actions over the additive ones for these characters. The prevalence of the non-additive variance suggesting heterosis breeding approach is effective way for improvement these traits. These results are in agreement with Mondal *et al* (2009), Kansouh and Zakher (2011), Katkar *et al* (2012), Kalenahalli and Gowda (2013), Shankar *et al* (2013), Saeed *et al* (2014), Dagade *et al* (2015) and Khalil *et al* (2015), who indicated the predominance of non-additive gene actions for the characters fruit set, total yield, average fruit weight, fruit firmness, total soluble solids, ascorbic acid and titratable acidity.

The data of Table 2 indicated that testers had lower proportional contribution than lines and lines x testers for all studied traits except TSS% trait. Results also showed that lines were more important for productive for the traits fruit set (47.86%), average fruits weight (47.77%), fruit firmness (53.93%), number of locules (68.79%) and TSS% (44.07%) which revealed predominance influence for these traits. However, the contribution of maternal and paternal interaction (Line x Tester) played higher important role higher than the individual contribution for the traits total yield (65.294%), marketable yield (58.081%) and vitamin C content (49.37).

3- Mean performance and better-parent heterosis (Heterobeltiosis):

Data obtained on performance of parents and their F_1 hybrids are presented in Table 3. Presented data showed significant differences for all studied traits among the evaluated genotypes.

The two testers T_1 and T_2 produced the highest significant fruit set percentage (86.69% and 83.95%, respectively) among all evaluated parents with non-significant differences between them. While, the line L_1 gave the lowest value (35.00%). Regarding crosses, $L_3 \times T_3$ and $L_7 \times T_1$ gave the highest fruit set values (80.37% and 79.84%, respectively) with non-significant differences between them. With regard to heterosis, only 3 crosses out of the 30 evaluated ones ($L_3 \times T_3$, $L_4 \times T_3$ and $L_6 \times T_3$) exhibited significant positive heterosis over better parent ranging from 16.3% to 35.9%.

For total yield, the line L_9 (18.014 ton) and tester T_1 gave maximum yield (17.131 ton) among all evaluated parents with non-significant differences between them. The hybrid $L_2 \times T_3$ produced the highest total yield (26.759 ton) among all evaluated hybrids followed, respectively, by the hybrids $L_3 \times T_3$ (25.981 ton) and $L_7 \times T_1$ (25.744 ton) with non-significant differences between them. For heterosis, 13 out of the evaluated hybrids showed significant positive heterosis ranging from 32.7 to 99.0% for the crosses $L_9 \times T_1$ and $L_4 \times T_3$, respectively.

The data on marketable yield trait showed that the tester T_1 produced the maximum marketable yield (16.261 ton) among all evaluated parents, followed by the line L_9 (14.555 ton) with non-significant differences between them. For hybrids, the highest significant marketable yield was produced by the hybrid $L_7 \times T_1$ (24.367 ton), followed by the hybrid $L_{10} \times T_1$ (22.539 ton) with non-significant differences between them. Concerning heterosis, 7 out of the 30 evaluated hybrids exhibited significant positive heterosis ranging from 21.4% to 71.0%.

Table 3. Mean performance and heterosis over better parent (BPH) for some economic characters of some tomato genotypes and their F_1's growing under heat stress.

Genotypes	Fruit set (%)		Total yield (ton/fed.)		Marketable yield (ton/fed.)		Average fruit weight (g)		Fruit shape index	
	M	BPH	M	BPH	M	BPH	M	BPH	M	BPH
L_1 (Ent 2)	35.00		9.617		8.600		64.07		0.90	
L_2 (Ent 3)	44.84		14.981		13.278		208.27		0.81	
L_3 (Ent 5)	38.93		15.367		13.000		65.60		1.08	
L_4 (Ent 8)	37.28		5.833		4.000		65.63		0.95	
L_5 (Ent 9)	44.15		8.292		4.333		65.33		0.95	
L_6 (Ent 12)	45.72		4.628		3.667		52.10		0.93	
L_7 (Ent 17)	62.96		17.659		13.547		66.90		0.89	
L_8 (Ent 28)	37.22		3.129		2.000		97.77		1.01	
L_9 (Ent 31)	64.72		18.014		14.555		109.07		0.85	
L_{10} (Ent 37)	71.15		15.990		12.000		92.97		0.94	
T_1 (TLB 111)	86.69		17.131		16.261		61.13		1.42	
T_2 (TLB 182-1)	83.95		15.120		13.500		57.47		1.07	
T_3 (99S-C-39)	59.12		11.541		9.467		25.10		1.12	
$L_1 \times T_1$	71.38	-17.7*	20.773	21.3	16.361	0.6	110.00	71.0*	0.88	-38.0*
$L_1 \times T_2$	47.83	-43.0*	19.333	27.9	17.500	29.6	80.00	24.9	0.89	-16.8*
$L_1 \times T_3$	50.37	-14.8*	18.012	56.1*	14.986	58.3*	84.00	31.1	0.86	-23.2*
$L_2 \times T_1$	63.62	-26.6*	19.869	16	16.375	0.7	111.47	-46.5*	0.93	-34.5*
$L_2 \times T_2$	44.62	-46.9*	17.037	12.7	10.592	-21.5	119.00	-42.9*	0.80	-25.2*
$L_2 \times T_3$	63.24	7.0	26.759	78.6*	17.178	29.4	91.97	-55.8*	0.95	-15.2*
$L_3 \times T_1$	76.90	-11.3*	19.716	15.1	15.389	-5.4	107.40	63.7*	1.12	-21.2*
$L_3 \times T_2$	67.59	-19.5*	18.165	18.2	14.400	6.7	86.27	31.5*	0.94	-13.0*
$L_3 \times T_3$	80.37	35.9*	25.981	69.1*	17.643	35.7*	79.13	20.6	1.00	-10.7*
$L_4 \times T_1$	71.41	-17.6*	20.283	18.4	14.683	-9.7	90.13	37.3*	0.95	-33.1*
$L_4 \times T_2$	48.91	-41.7*	20.670	36.7*	17.259	27.8	89.00	35.6*	0.91	-15.0*
$L_4 \times T_3$	74.38	25.8*	22.971	99.0*	15.677	65.6*	82.47	25.7	1.01	-9.8*
$L_5 \times T_1$	74.44	-14.1*	21.214	23.8	16.772	3.1	103.17	57.9*	0.95	-33.1*
$L_5 \times T_2$	78.18	-6.9	22.179	46.7*	16.179	19.8	104.27	59.6*	0.89	-16.8*
$L_5 \times T_3$	64.48	9.1	17.611	52.6*	13.111	38.5	69.83	6.9	0.97	-13.4*
$L_6 \times T_1$	55.76	-35.7*	15.445	-9.8	14.481	-11.0	54.97	-10.1	1.20	-15.5*
$L_6 \times T_2$	55.79	-33.5*	19.375	28.1	14.350	6.3	75.73	31.8*	0.96	-10.3*
$L_6 \times T_3$	68.75	16.3*	17.993	55.9*	13.993	47.8*	56.70	8.8	0.93	-17.0*
$L_7 \times T_1$	79.84	-7.9	25.744	45.8*	24.367	49.9*	99.60	48.9*	0.97	-31.7*
$L_7 \times T_2$	75.71	-9.8*	22.056	24.9	17.233	27.2	86.87	29.9*	0.92	-14.0*
$L_7 \times T_3$	68.90	9.4	18.211	3.1	13.055	-3.6	81.30	21.5	0.90	-19.6*
$L_8 \times T_1$	69.84	-19.4*	19.737	15.2	13.307	-18.2	72.33	-26.0*	0.93	-34.5*
$L_8 \times T_2$	68.89	-17.9*	18.809	24.4	13.910	3.0	89.67	-8.3	0.89	-16.8*
$L_8 \times T_3$	63.14	6.8	18.151	57.3*	13.150	38.9	90.200	-7.7	0.93	-17.0*
$L_9 \times T_1$	57.25	-44.0*	23.910	32.7*	20.952	28.9*	63.200	-42.1*	1.21	-14.8*
$L_9 \times T_2$	52.09	-38.0*	15.989	-11.2	12.700	-12.8	105.300	-3.5	0.91	-15.0*
$L_9 \times T_3$	66.89	3.4	15.574	-13.5	11.648	-20.0	68.900	-36.8*	0.98	-12.5*
$L_{10} \times T_1$	66.67	-23.1*	24.960	45.7*	22.539	38.6*	112.833	21.4*	0.98	-31.0*
$L_{10} \times T_2$	57.89	-31.0*	20.486	28.1	15.829	17.3	86.933	-6.5	1.01	-5.6
$L_{10} \times T_3$	62.74	-11.8*	23.777	46.7*	13.870	15.6	95.867	3.1	0.94	-16.1*
LSD (5%)	6.89		5.028		4.148		17.2		0.10	

Table 3. Continue.

Genotypes	Fruit firmness (g/cm^2)		No. locules		TSS%		Vitamin C content (mg /100 g fresh fruit)		Titratable Acidity (mg citric acid/100 g fresh fruit)	
	M	BPH	M	BPH	M	BPH	M	BPH	M	BPH
L_1 (Ent 2)	325.0		5.7		4.7		20.7		0.62	
L_2 (Ent 3)	451.0		7.1		4.7		16.5		0.92	
L_3 (Ent 5)	642.0		4.8		4.4		18.2		0.72	
L_4 (Ent 8)	525.0		4.2		5.0		20.0		0.88	
L_5 (Ent 9)	412.0		5.3		4.2		20.4		0.65	
L_6 (Ent 12)	364.0		3.3		5.3		19.6		0.83	
L_7 (Ent 17)	563.0		4.6		4.2		20.4		1.04	
L_8 (Ent 28)	488.0		5.4		4.6		18.4		0.77	
L_9 (Ent 31)	635.0		6.3		4.1		20.3		0.73	
L_{10} (Ent 37)	542.0		5.9		4.1		15.3		0.71	
T_1 (TLB 111)	483.0		2.2		4.4		15.0		0.59	
T_2 (TLB 182-1)	405.0		2.6		4.5		18.2		0.84	
T_3 (99S-C-39)	414.0		2.9		5.5		17.7		1.01	
L_1× T_1	432.0	-10.6	5.0	-12.2	4.3	-8.5*	16.8	-18.9*	0.74	19.4
L_1× T_2	437.0	-7.9	4.5	-21.1	4.8	2.1	17.4	-15.9*	0.83	-1.2
L_1× T_3	425.0	2.7	5.9	3.5	5.3	-3.6	19.6	-5.3	0.74	-26.7*
L_2× T_1	618.0	28.0*	5.1	-28.2*	4.4	-6.4*	14.8	-10.3*	0.78	-15.2
L_2× T_2	520.0	15.3*	5.7	-19.7*	4.3	-8.5*	15.4	-15.4*	0.72	-21.7*
L_2× T_3	422.0	-6.4	4.4	-38.0*	4.7	-14.6*	24.2	36.7*	0.71	-29.7*
L_3× T_1	575.0	-10.4*	3.5	-27.1*	4.4	0.0	19.1	5.0	0.70	-2.8
L_3× T_2	563.0	-12.3*	4.5	-6.3	4.1	-8.8*	20.9	14.8*	0.74	-11.9
L_3× T_3	580.0	-9.7*	4.0	-16.7	4.3	-21.8*	15.9	12.6*	0.79	-21.8*
L_4× T_1	504.0	-4.0	4.0	-4.8	4.4	-12.0*	16.9	-15.5*	0.74	-15.9
L_4× T_2	610.0	16.2*	3.9	-7.1	4.6	-8.7*	20.6	3.0	0.84	-4.6
L_4× T_3	490.0	-6.7	4.0	-4.8	4.8	-12.7*	23.6	18.0*	0.74	-26.7*
L_5× T_1	534.0	10.6	4.6	-13.2	4.0	-9.1*	16.2	-20.6*	0.72	10.8
L_5× T_2	445.0	8.0	4.3	-18.9	4.4	-2.2	15.5	-24.0*	0.77	-8.3
L_5× T_3	451.0	8.9	4.2	-20.8	4.7	-14.6*	17.6	-13.7*	0.80	-20.8*
L_6× T_1	544.0	12.6*	2.4	-27.3	4.8	-9.4*	21.3	8.7*	0.70	-15.7
L_6× T_2	605.0	49.4*	3.4	3.0	4.8	-9.4*	21.6	10.2*	0.54	-35.7*
L_6× T_3	525.0	26.8*	3.1	-6.1	4.7	-14.6*	18.9	-3.6	1.04	3.0
L_7× T_1	515.0	-8.5	4.3	-6.5	4.0	-9.0*	18.4	-9.8*	0.58	-44.2*
L_7× T_2	575.0	2.1	4.2	-8.7	4.4	-2.2	18.0	-11.8*	0.68	-34.6*
L_7× T_3	427.0	-24.2*	3.7	-19.6	4.7	-14.6*	15.7	-23.0*	0.92	-11.5
L_8× T_1	383.0	-21.5*	4.6	-14.8	4.5	-2.2	10.5	-42.9*	0.84	9.1
L_8× T_2	465.0	-4.7	5.1	-5.6	4.4	-4.4	17.3	-6.0	0.55	-34.5*
L_8× T_3	325.0	-33.4*	4.5	-16.7	5.0	-9.1*	19.7	7.1	0.61	-39.6*
L_9× T_1	399.0	-37.2*	2.8	-55.6*	4.3	-2.3	12.0	-40.9*	0.70	-4.1
L_9× T_2	541.0	-14.8*	4.9	-22.2*	4.4	-2.2	18.8	-7.4*	0.53	-36.9*
L_9× T_3	336.0	-47.1*	3.8	-39.7*	4.7	-14.6*	18.8	-7.4*	0.78	-22.8*
L_{10}× T_1	470.0	-13.3*	5.2	-11.9	4.1	-6.8*	12.2	-20.3*	0.73	2.8
L_{10}× T_2	565.0	4.2	5.1	-13.6	4.3	-4.4	16.8	-7.7*	0.83	-1.2
L_{10}× T_3	514.0	-5.2	4.7	-20.3	4.2	-23.6*	17.2	-2.8	0.62	-38.6*
LSD (5%)	55.8		1.3		0.3		1.4		0.15	

The highest average fruit weight was found in fruits of the line L_2 (208.27 g) among all evaluated parents. Regarding hybrids, $L_2 \times T_2$ (119.00 g) gave the heaviest fruits followed by the hybrid $L_{10} \times T_1$ (112.833 g) with non-significant differences between them.

In case of fruit shape index trait, only the tester T_1 had oval fruits, meanwhile, the other testers T_2 and T_3 and all lines had round or oblate fruits, meanwhile, all evaluated hybrids gave round or oblate fruits. None of the 30 hybrids were superior for fruit shape index trait.

Fruit firmness of the evaluated parents ranged from 325.0 g/cm^2 (L_1) to 642.0 g/cm^2 (L_3). The genotypes L_3 and L_9 had the highest fruit firmness among all evaluated parents, however, the hybrids $L_2 \times T_1$ and $L_4 \times T_2$ gave the highest fruit firmness (618.0 and 610 g/cm^2, respectively) among all evaluated hybrids without significant differences between them. Six out of the 30 evaluated hybrids showed significant positive heterosis for fruit firmness ranged from 12.6% to 49.4%.

The lines L_2, L_9 and L_{10}, significantly, had the highest number of locules among parents without significant differences between them. For hybrids, the hybrid $L_1 \times T_3$, significantly, had the highest number of locules (5.9) followed by $L_2 \times T_2$ (5.7) without significant differences between them. None of the 30 hybrids were superior for number of locules trait.

For TSS% trait, the highest TSS value of parents was detected in fruits of the tester T_3 (5.5%), meanwhile, the hybrid $L_1 \times T_3$ had the highest TSS% (5.3%) followed by the hybrid $L_8 \times T_3$ (5.0%) with significant differences between them. None of the 30 hybrids were superior for TSS% trait.

Regarding ascorbic acid content trait, fruits of the line L_1 had the highest ascorbic acid content (20.7 mg/100 g fresh fruit) among evaluated parents followed by the lines L_5 and L_7 (20.4 mg/100 g fresh fruit) without significant differences between them, however, the hybrid $L_2 \times T_3$ had, significantly, the highest ascorbic acid content (24.2 mg/100 g fresh fruit) among all evaluated hybrids followed by the hybrid $L_4 \times T_3$ (23.6 mg/100 g fresh fruit) without significant differences between them. Six out of the 30 evaluated hybrids showed significant positive heterosis for ascorbic acid content ranging from 8.7% to 36.7%, respectively.

In case of titratable acidity trait, fruits of the line L_7 had, significantly, the highest titratable acidity (1.04 mg/100 g fresh fruit) among evaluated parents, however the hybrid $L_6 \times T_3$ had, significantly, the highest titratable acidity (1.04 mg/100 g fresh fruit) among all evaluated hybrids followed by the hybrid $L_7 \times T_3$ (0.92 mg/100 g fresh fruit) without significant differences between them. None of the 30 hybrids were superior for titratable acidity trait.

These results are partially in agreement with the findings of Mondal *et al* (2009), Shalaby (2012), Kalenahalli and Gowda (2013), Saeed *et al* (2014) and Khalil *et al* (2015) who found heterosis over better parent in tomato for the traits fruit set, total yield per plant average fruit weight, fruit firmness and TSS. However, heterosis was found absent for average fruit weight (Shalaby 2012), for fruit yield, TSS, and fruit firmness (Kalenahalli and Gowda 2013) and for fruit set trait (Khalil *et al* 2015).

4- General Combining Ability Effects of Parents:

Estimation of general combining ability (GCA) provides basic and important information for exploiting genetic potential of parents for development of superior lines. As expression of significant and high GCA effects of a parent line reflects the presence of favorable additive genes with additive genetic effects that leads to selection in early generations for developing widely adapted hybrids (Roy *et al* 2002). Estimation of GCA effects of lines and testers represented that no single line or tester exhibited good general combining ability for all the traits (Table 4). Among the lines, the highest values of GCA effects were shown by the line L_3 for fruit set percentage, fruit firmness and ascorbic acid content traits. The line L_{10} gave the highest values for total yield and average fruit weight, while the line L_7 had the highest GCA effects for marketable yield trait. The line L_9 gave the highest values for fruit shape index trait, while, the line L_1 had the highest number of locules per fruit and TSS traits. The line L_6 gave the highest values for ascorbic acid content trait. Similarly among the testers, T_1 had the highest values for fruit set percentage, total yield, marketable yield, average fruit weight and fruit shape index. While, the line T_2 gave the highest values for fruit firmniss and number of locules/fruit. However, the highest values of GCA effects were shown by the line T_3 for TSS, ascorbic acid content and titratable acidity traits. According to these results, lines L_3 and L_7 and the tester T_1 showed maximum positive GCA effects for most of the important traits. So, these parents could be successfully used in future breeding programs.

5- Specific Combining Ability Effects of Hybrids:

The specific combining ability reveals the best cross combinations which can be useful for developing hybrids with high vigour for the traits. Significant superior SCA effects for all studied traits were not shown by a single hybrid. The data obtained in Table 5 indicated that the F_1 crosses $L_1 \times T_1$, $L_4 \times T_3$, $L_5 \times T_2$, $L_6 \times T_3$, $L_7 \times T_2$, $L_8 \times T_2$ and $L_9 \times T_3$ achieved significant positive SCA effects for fruit set percentage. Only three crosses ($L_2 \times T_3$, $L_3 \times T_3$ and $L_9 \times T_1$) showed significant SCA effects for total yield. Five crosses ($L_2 \times T_3$, $L_3 \times T_3$, $L_7 \times T_1$, $L_9 \times T_1$ and $L_{10} \times T_1$) showed significant SCA effects for marketable yield. Eleven hybrids exhibited significant SCA effects for heavy fruits and the cross $L_9 \times T_2$ showed the highest significant value. The hybrid $L_9 \times T_1$ showed the highest significant SCA effect for fruit shape index trait. Four crosses ($L_2 \times T_1$, $L_3 \times T_3$, $L_5 \times T_1$ and $L_9 \times T_2$) had significant positive SCA effects for fruit firmness trait. None of crosses showed significant SCA effect for number of locules/fruit trait. Only two crosses, *viz*., $L_1 \times T_3$ and $L_3 \times T_1$ showed significant positive SCA effects for TSS trait. Significant positive SCA effects were observed in nine crosses for ascorbic acid content trait and the hybrid $L_2 \times T_3$ had the highest value. For titratable acidity trait, the SCA effects for $L_6 \times T_3$, $L_7 \times T_3$, $L_8 \times T_1$ and $L_{10} \times T_2$ were significant and positive. Among all hybrids, $L_2 \times T_3$, $L_3 \times T_3$ and $L_9 \times T_1$ exhibited significant SCA effects for both total and marketable yield characters. So, these hybrids can be used in future breeding program.

CONCLUSION

From this study, it can be concluded that the lines Ent 5 and Ent 17 and the tester TLB 111 showed maximum positive GCA effects for most of the important traits under heat stress. So, these parents could be successfully used in future breeding programs. Also, among all crosses, Ent 3 × 99S-C-39, Ent 5 × 99S-C-39 and Ent 31 × TLB 111 exhibited significant SCA effects for both total and marketable yield characters under heat stress. So, these hybrids can be used in future breeding program.

Table 4. Estimation of parental general combining ability (GCA) effects for some tomato characters growing under heat stress.

Genotypes	Fruit Set	Total yield	Marketable yield	Average fruit weight	Fruit shape	Fruit firmness	No. locules	TSS	Vitamin C content	Titratable Acidity
Lines (Females)										
L_1 (Ent 2)	-8.40*	-0.99	0.63	3.05*	-0.083*	-61.83*	0.82*	0.301*	0.22	0.034
L_2 (Ent 3)	-7.77*	0.86	-0.93	19.19*	-0.065*	26.83*	0.73*	-0.038	0.39	0.003
L_3 (Ent 5)	10.02*	0.93	0.16	2.65*	0.063*	79.50*	-0.29	-0.232*	0.94*	0.011
L_4 (Ent 8)	-0.03	0.95	0.22	-1.09	-0.001	41.50*	-0.33	0.129	2.64*	0.040
L_5 (Ent 9)	7.44*	-0.02	-0.30	4.14*	-0.020	-16.50	0.04	-0.093	-1.29*	0.031
L_6 (Ent 12)	-4.83*	-2.76*	-1.38	-25.82*	0.073*	64.83*	-1.34*	0.273*	2.87*	0.025
L_7 (Ent 17)	9.89*	1.64	2.57*	0.99	-0.027*	12.50	-0.26	-0.104	-0.38	-0.005
L_8 (Ent 28)	2.36	-1.46	-2.19*	-4.22*	-0.038*	-102.17*	0.42	0.112	-1.92*	-0.067*
L_9 (Ent 31)	-6.19*	-1.87	-0.55	-9.15*	0.077*	-67.83*	-0.48	-0.038	-1.18*	-0.066*
L_{10} (Ent 37)	-2.50	2.71*	1.76	10.26*	0.021	23.17*	0.68*	-0.310*	-2.30*	-0.006
LSD 5%	**2.81**	**2.05**	**1.69**	**2.36**	**0.026**	**22.78**	**0.55**	**0.134**	**0.57**	**0.061**
Testers (Males)										
T_1 (TLB 111)	3.78*	0.81	1.87*	4.22*	0.055*	4.23	-0.17	-0.168*	-1.90*	-0.011
T_2 (TLB 182-1)	-5.18*	-0.95	-0.65	4.02*	-0.044*	39.43*	0.25	-0.040	0.51*	-0.031
T_3 (99S-C-39)	1.40	0.14	-1.22*	-8.25*	-0.011	-43.67*	-0.08	0.208*	1.39*	0.042*
LSD 5%	**1.54**	**1.12**	**0.93**	**1.29**	**0.014**	**12.48**	**0.30**	**0.074**	**0.31**	**0.033**

NS,*,**: insignificant, significant and highly significant at 0.05 and 0.01 level of probability, respectively.

Table 5. Estimation of specific combining ability (SCA) effects for some tomato characters growing under heat stress.

Crosses	Fruit Set	Total yield	Marketable yield	Average fruit weight	Fruit shape	Fruit firmness	No. locules	TSS	Vitamin C content	Titratable Acidity
$L_1 \times T_1$	11.07*	0.59	-1.79	14.44*	-0.047*	-3.57	0.04	-0.293*	0.79	-0.020
$L_1 \times T_2$	-3.52	0.91	1.87	-15.36*	0.056*	-33.77	-0.89	0.046	-1.08*	0.093
$L_1 \times T_3$	-7.55*	-1.51	-0.08	0.92	-0.008	37.33	0.85	0.247*	0.29	-0.073
$L_2 \times T_1$	2.68	-2.16	-0.21	-0.24	-0.021	93.77*	0.23	0.079	-1.45*	0.055
$L_2 \times T_2$	-7.36*	-3.23	-3.47*	7.50*	-0.047*	-39.43	0.37	-0.149	-3.21*	0.011
$L_2 \times T_3$	4.69	5.39*	3.68*	-7.26*	0.067*	-54.33*	-0.60*	0.069	4.66*	-0.066
$L_3 \times T_1$	-1.84	-2.38	-2.29	12.24*	0.041	-1.90	-0.32	0.257*	2.37*	-0.033
$L_3 \times T_2$	-2.18	-2.17	-0.76	-8.69*	-0.034	-49.10*	0.26	-0.088	1.77*	0.030
$L_3 \times T_3$	4.02	4.55*	3.05*	-3.55	-0.007	51.00*	0.06	-0.169	-4.13*	0.003
$L_4 \times T_1$	2.73	-1.83	-3.06*	-1.29	-0.060*	-34.90	0.19	-0.054	-1.53*	-0.025
$L_4 \times T_2$	-10.81*	0.31	2.04	-2.22	0.001	35.90	-0.30	0.051	-0.29	0.101
$L_4 \times T_3$	8.08*	1.52	1.02	3.52	0.060*	-1.00	0.10	0.003	1.82*	-0.076
$L_5 \times T_1$	-1.71	0.07	-0.46	6.52*	-0.044	53.10*	0.38	-0.198	1.67*	-0.033
$L_5 \times T_2$	10.99*	2.79	1.48	7.82*	0.001	-71.10*	-0.27	0.073	-1.45*	0.037
$L_5 \times T_3$	-9.28*	-2.87	-1.02	-14.34*	0.044	18.00	-0.11	0.125	-0.22	-0.003
$L_6 \times T_1$	-8.12*	-2.96	-1.67	-11.72*	0.118*	-18.23	-0.40	0.202	2.59*	-0.051
$L_6 \times T_2$	0.87	2.72	0.73	9.24*	-0.031	7.57	0.15	0.073	0.51	-0.191*
$L_6 \times T_3$	7.26*	0.24	0.94	2.48	-0.088*	10.67	0.25	-0.275*	-3.10*	0.242*
$L_7 \times T_1$	1.24	2.94	4.28*	6.10*	-0.016	5.10	0.38	-0.187	2.95*	-0.134*
$L_7 \times T_2$	6.07*	1.00	-0.33	-6.37*	0.034	29.90	-0.11	0.084	0.12	-0.018
$L_7 \times T_3$	-7.31*	-3.94*	-3.94*	0.27	-0.017	-35.00	-0.27	0.103	-3.07*	0.152*
$L_8 \times T_1$	-1.23	0.03	-2.02	-15.96*	-0.041	-12.23	0.00	0.029	-3.44*	0.185*
$L_8 \times T_2$	6.78*	0.86	1.11	1.58	0.018	34.57	0.15	-0.166	0.96	-0.086
$L_8 \times T_3$	-5.55*	-0.89	0.91	14.38*	0.023	-22.33	-0.15	0.136	2.49*	-0.099
$L_9 \times T_1$	-5.27*	4.61*	3.98*	-20.16*	0.122*	-30.57	-0.86	0.046	-2.64*	0.040
$L_9 \times T_2$	-1.47	-1.55	-1.75	22.14*	-0.076	76.23*	0.78	-0.049	1.77*	-0.110*
$L_9 \times T_3$	6.75*	-3.06	-2.23	-1.98	-0.046*	-45.67	0.08	0.003	0.87	0.070
$L_{10} \times T_1$	0.45	1.08	3.25*	10.06*	-0.051*	-50.57*	0.35	0.118	-1.31*	0.017
$L_{10} \times T_2$	0.64	-1.64	-0.93	-15.64*	0.078*	9.23	-0.14	0.123	0.91	0.133*
$L_{10} \times T_3$	-1.09	0.56	-2.32	5.57*	-0.027	41.33	-0.21	-0.242*	0.40	-0.150*
LSD 5%	**4.87**	**3.56**	**2.93**	**4.08**	**0.045**	**39.45**	**0.95**	**0.232**	**0.99**	**0.105**

Note: Ent 2 (L_1), Ent 3 (L_2), Ent 5 (L_3), Ent 8 (L_4), Ent 9 (L_5), Ent 12 (L_6), Ent 17 (L_7), Ent 28 (L_8), Ent 31 (L_9), Ent 37 (L_{10}), TLB 111 (T_1), TLB 182-1 (T_2) and 99S-C-39 (T_3)

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القدرة على التآلف وقوة الهجين فى الطماطم تحت ظروف الحرارة المرتفعة

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الملخص العربى

أجريت هذه الدراسة بمحافظة القليوبية خلال عامى 2014 ، 2015 وذلك بهدف استنباط بعض هجن من الطماطم المبشرة للمحصول العالى وصفات الجودة تحت ظروف الحرارة المرتفعة فى مصر بإستخدام طريقة التهجين القمى. أظهرت الدراسة وجود تطابق إلى حد كبير بين قيم كل من التباين الوراثى مع التباين الكلى وبين معامل الاختلاف الوراثى مع معامل الاختلاف الكلى والتى تم تأكيدها بنتائج نسبة معامل الاختلاف الوراثى / معامل الاختلاف الكلى ونسبة التوريث العالية فى كل الصفات المدروسة وهى نسبة العقد ، والمحصول الكلى ، والمحصول القابل للتسويق ، ومتوسط وزن الثمرة ، وشكل الثمرة ، وعدد المساكن بالثمرة ، وصلابة الثمرة ، والمواد الصلبة الذائبة الكلية ، وفيتامين ج ، والحموضة مما يؤكد ضعف التأثير البيئى على هذه الصفات وأن معظم التأثير يرجع للتركيب الوراثى وذلك فى كل الصفات المدروسة ما عدا صفتى عدد المساكن بالثمرة والحموضة الكلية واللاتى تأثرتا بكلا من البيئة والوراثة. وقد أظهرت الدراسة أيضا أهمية كل من الفعل المضيف وغير المضيف للجينات فى وراثة كل الصفات المدروسة مع الأخذ فى الاعتبار أن الجزء غير المضيف للجينات هو الأهم مما يؤكد على أهمية دور قوة الهجين فى برامج التربية لهذة الصفات. أظهرت بعض الهجن قوة هجين معنوية بالمقارنة بالأب الأفضل لمعظم الصفات. أظهرت السلالات L_3 ، L_7 و T_1 ، قدرة عامة موجبة على التآلف لمعظم الصفات مما يؤكد امكانية استخدامها كآباء في برامج التربية. و قد أظهرت الهجن $L_2 \times T_3$ ، $L_3 \times T_3$ و $L_9 \times T_1$ ، قدرة خاصة على التآلف للمحصول الكلي والقابل للتسويق وبالتالى امكانية استخدام تلك الهجن فى برامج التربية فى المستقبل.